

Oxygen-depleted water in the Columbia River estuary: Observations and consequences



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**Estuary Partnership
Science Work Shop
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Overview of talk

- Overview of dissolved oxygen
- Columbia River measurements
- Consequences for migrating salmon and crab
- Summary and management implications

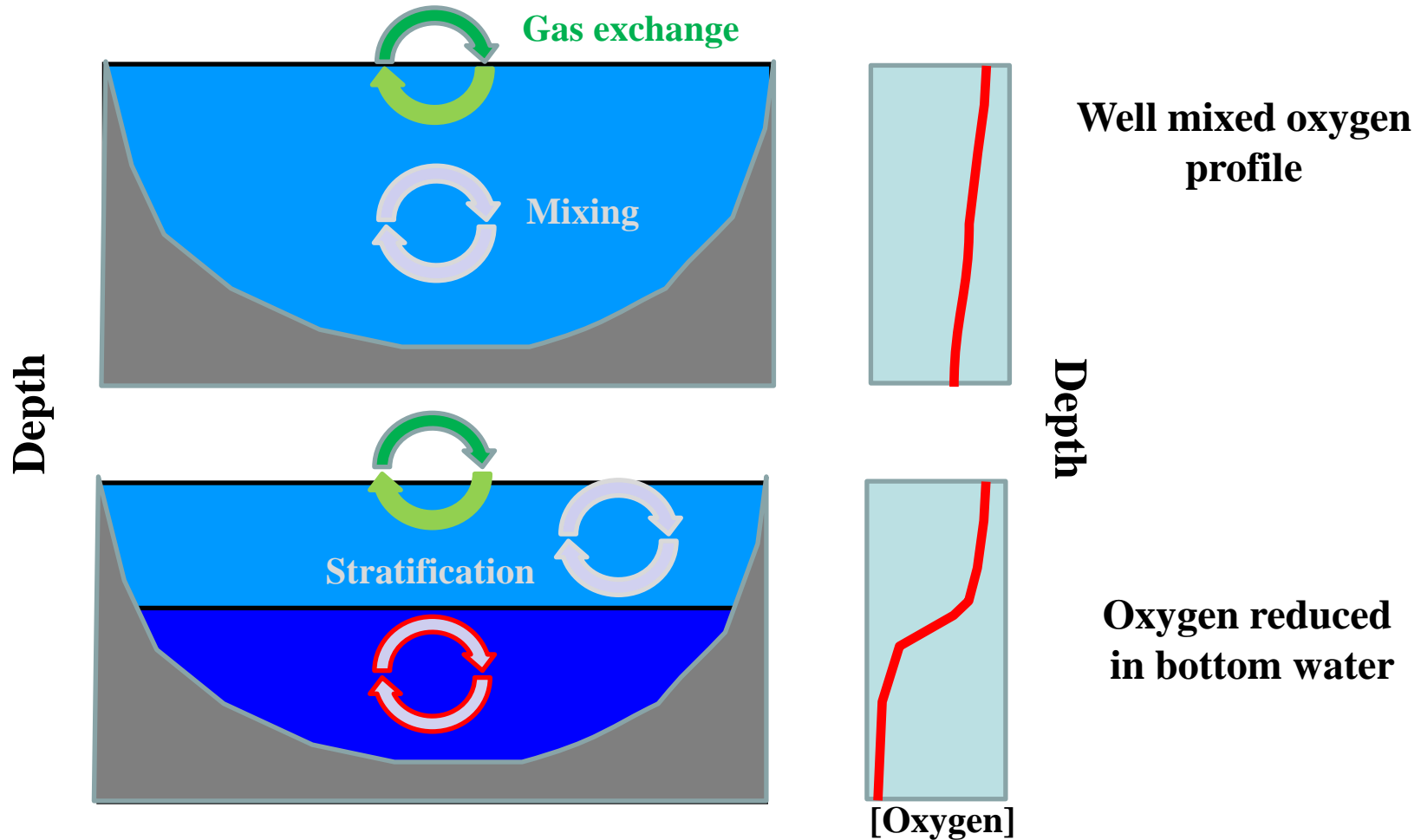


Juvenile salmon



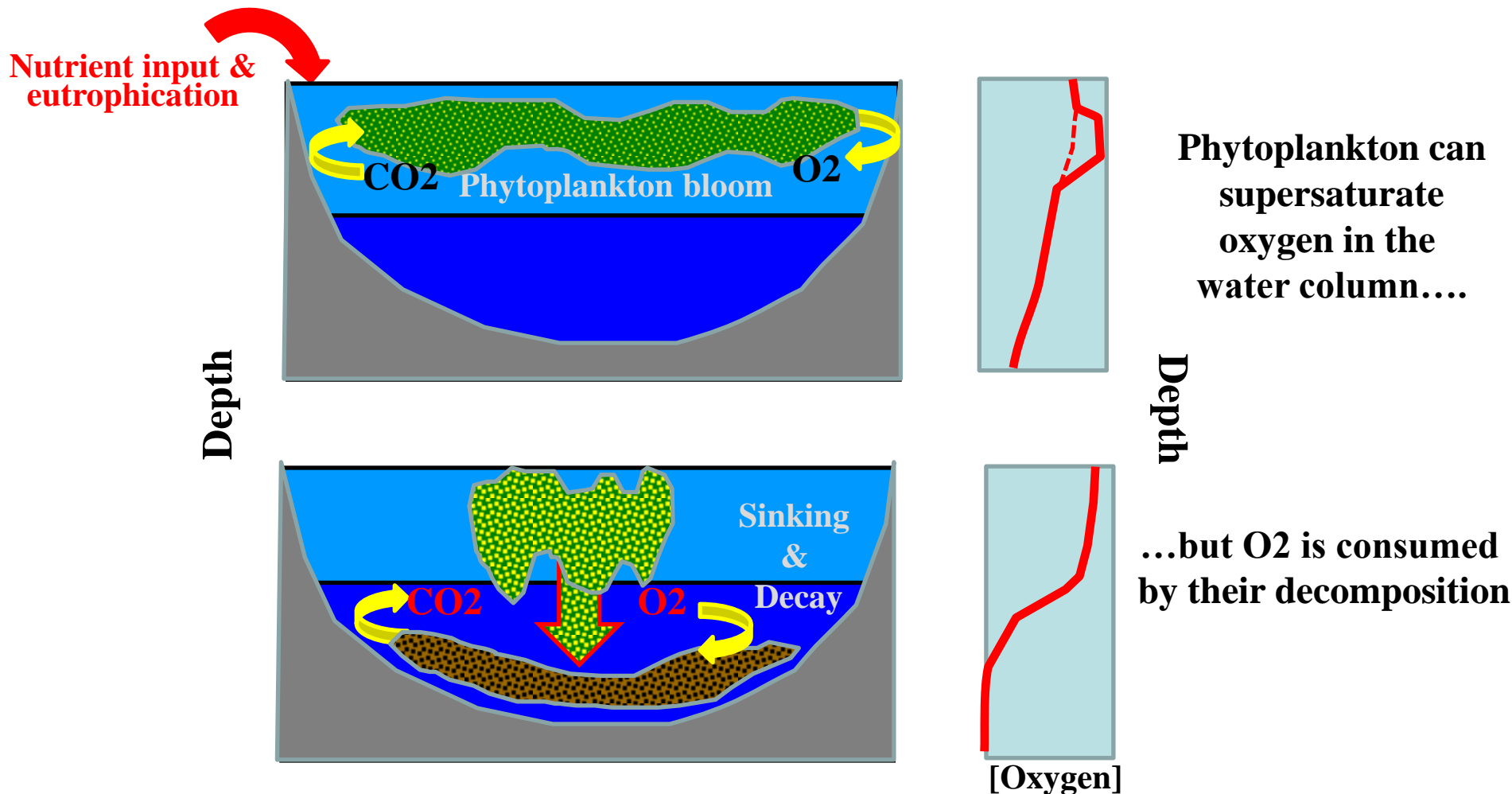
Dungeness crab

Stratification limits oxygen exchange



- Organic matter decomposition uses O₂ and produces CO₂
- Mixing by wind, tides, river flow can limit stratification
- Stratification enhanced by temperature and salinity gradients

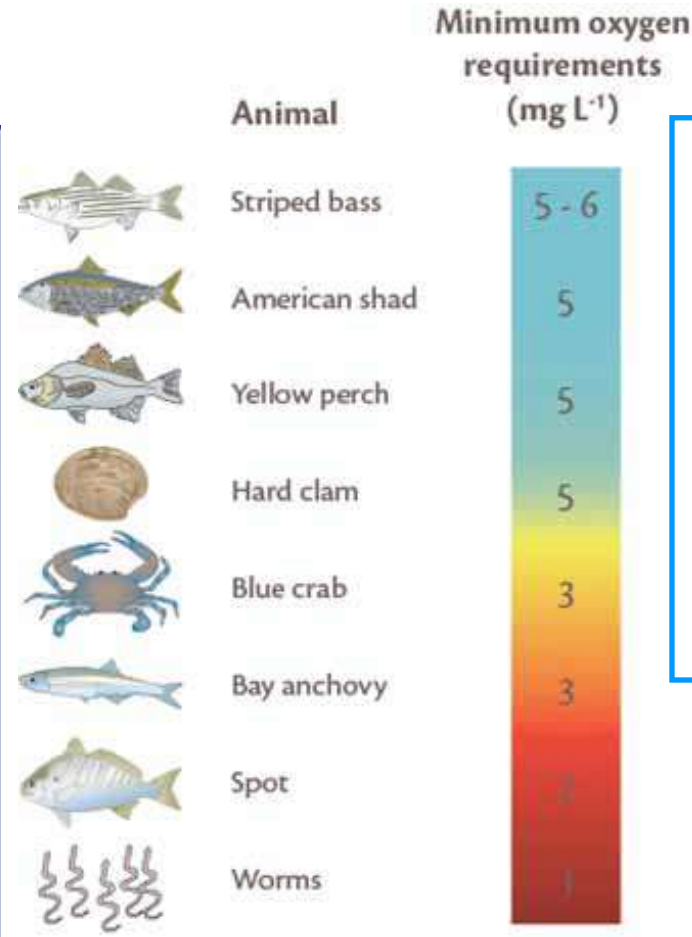
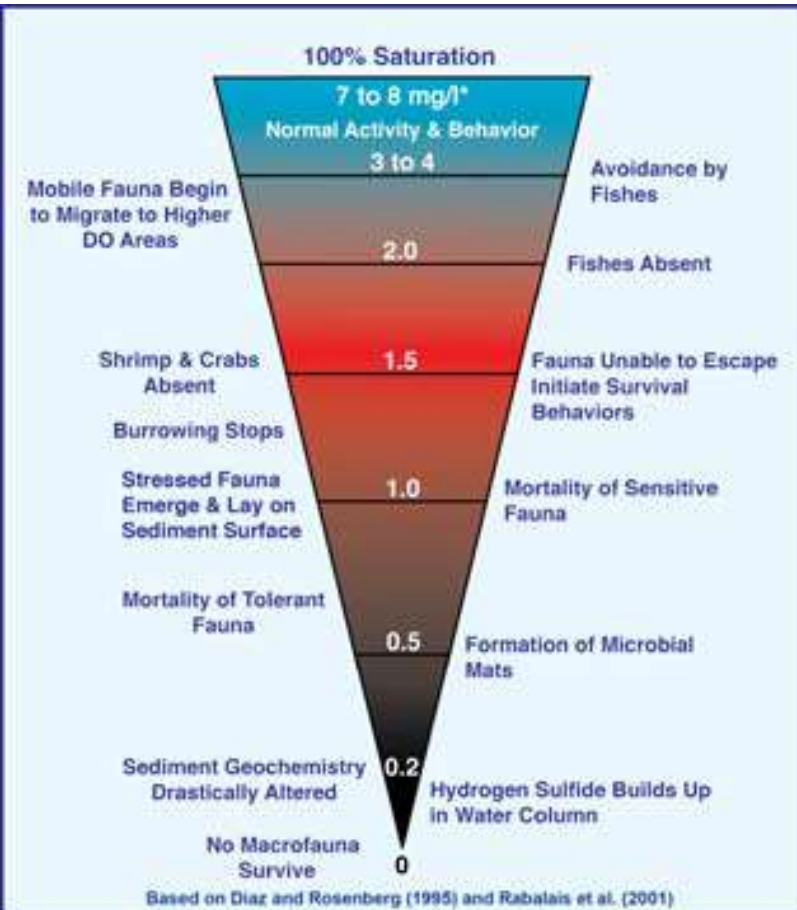
Organic matter decomposition leads to low dissolved oxygen



- Heterotrophic respiration in poorly ventilated water is what causes low DO in lakes, estuaries and the oceans.

Effect of low DO on biota: Differential susceptibility

- Overview
- Columbia River measurements
- Consequences for migrating salmon and crab
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- Sublethal effects:**
- Migration
 - Quiescence
 - Reduced feeding and growth
 - Altered predator – prey relationships

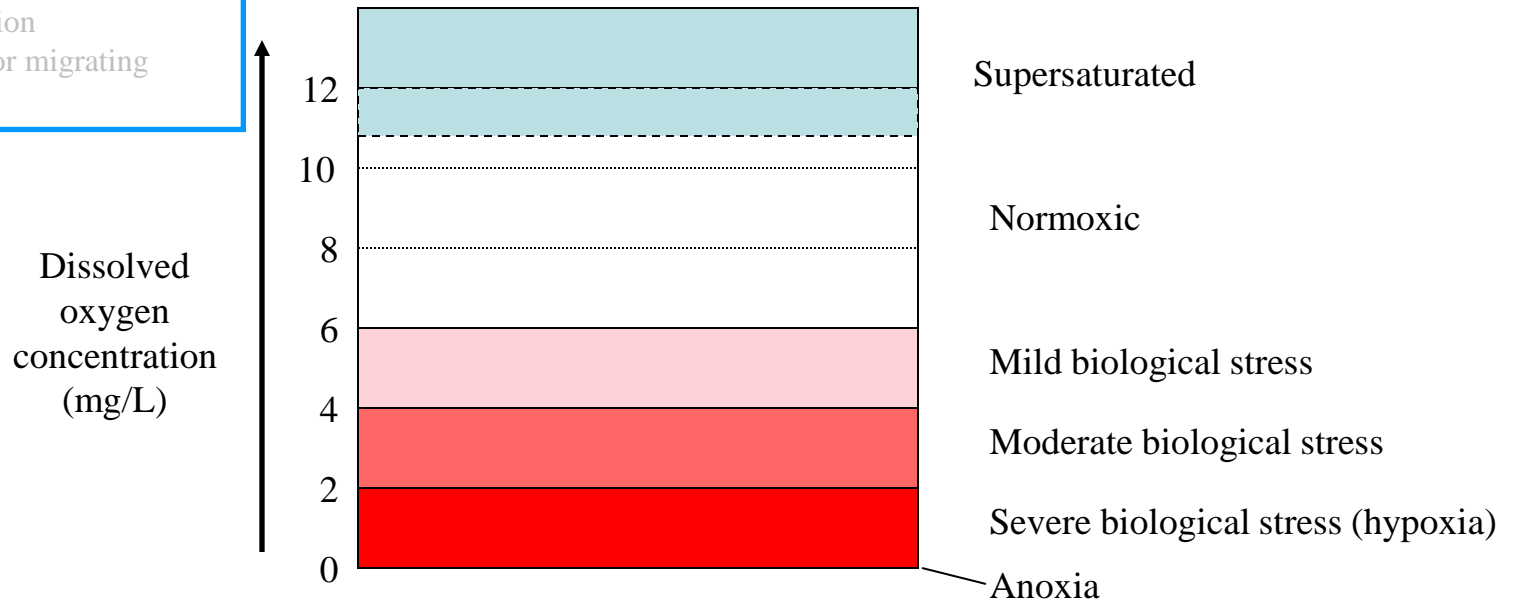
*Minimum dissolved oxygen requirements for key organisms in Chesapeake Bay

Characterization of DO levels

- Estuarine-ocean linkage and physical drivers
- Characterization of DO levels – biological perspective
- DO observations in the CRE 2006-2008
- Oxygen production
- Consequences for migrating salmon and crab

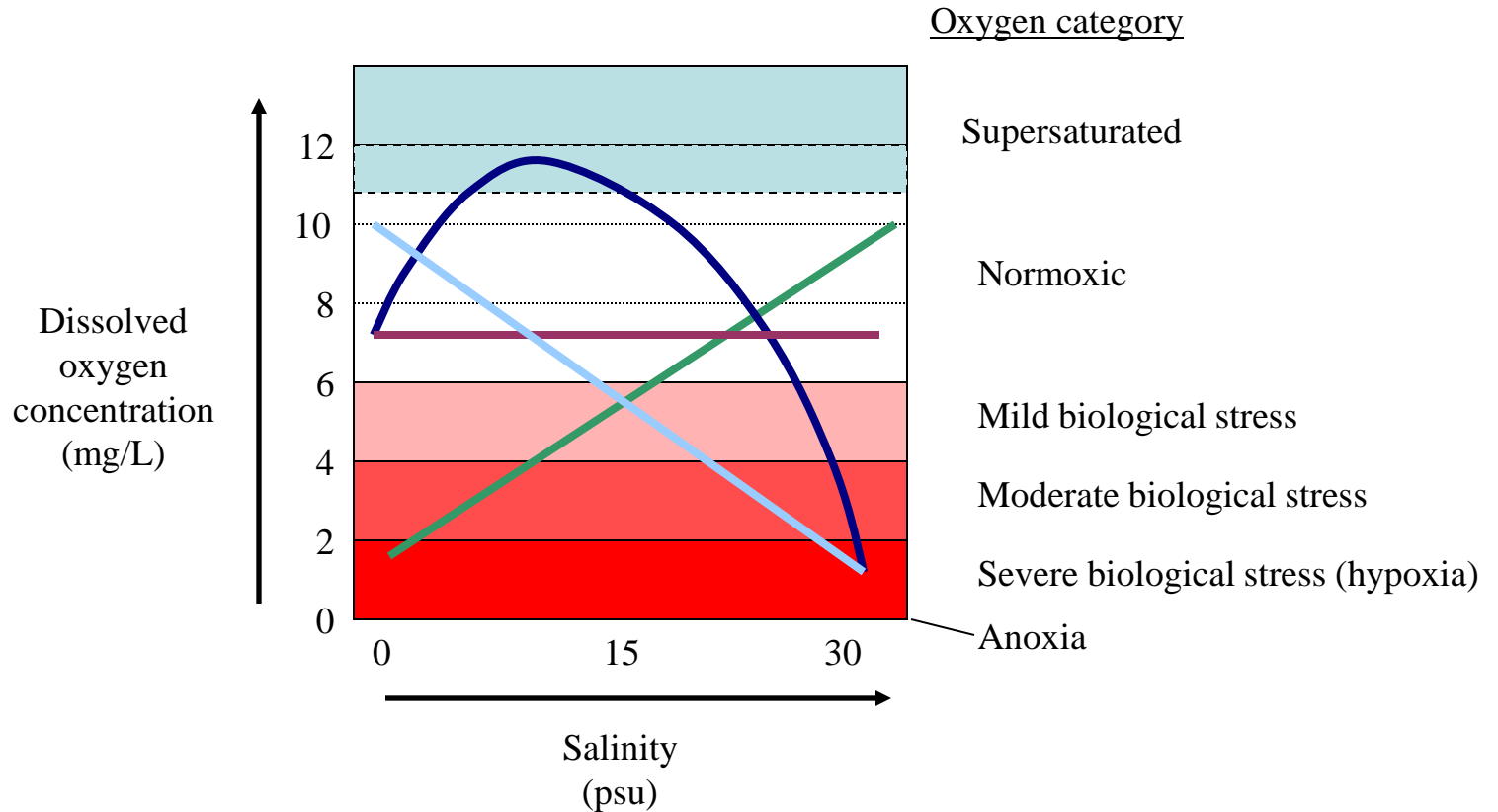


Oxygen category



- Juvenile salmon prefer > 9 mg/L and avoid 6 mg/L
- Reduced swimming speed and growth < 4 mg/L
- Dungeness crabs reduce activity $\sim 50\%$ saturation

Dissolved oxygen sources and sinks



- No relation to salinity
- Conservative (linear mixing) with reduced DO in ocean end-member
- Conservative (linear mixing) with reduced DO in river end-member
- Non-conservative mixing with an estuarine source

Dissolved oxygen observations in the CRE

- Definitions
- Columbia River measurements
- Consequences for migrating salmon and crab
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■ Data sources

■ Shipborne sensors

- CTD from transects or anchor stations

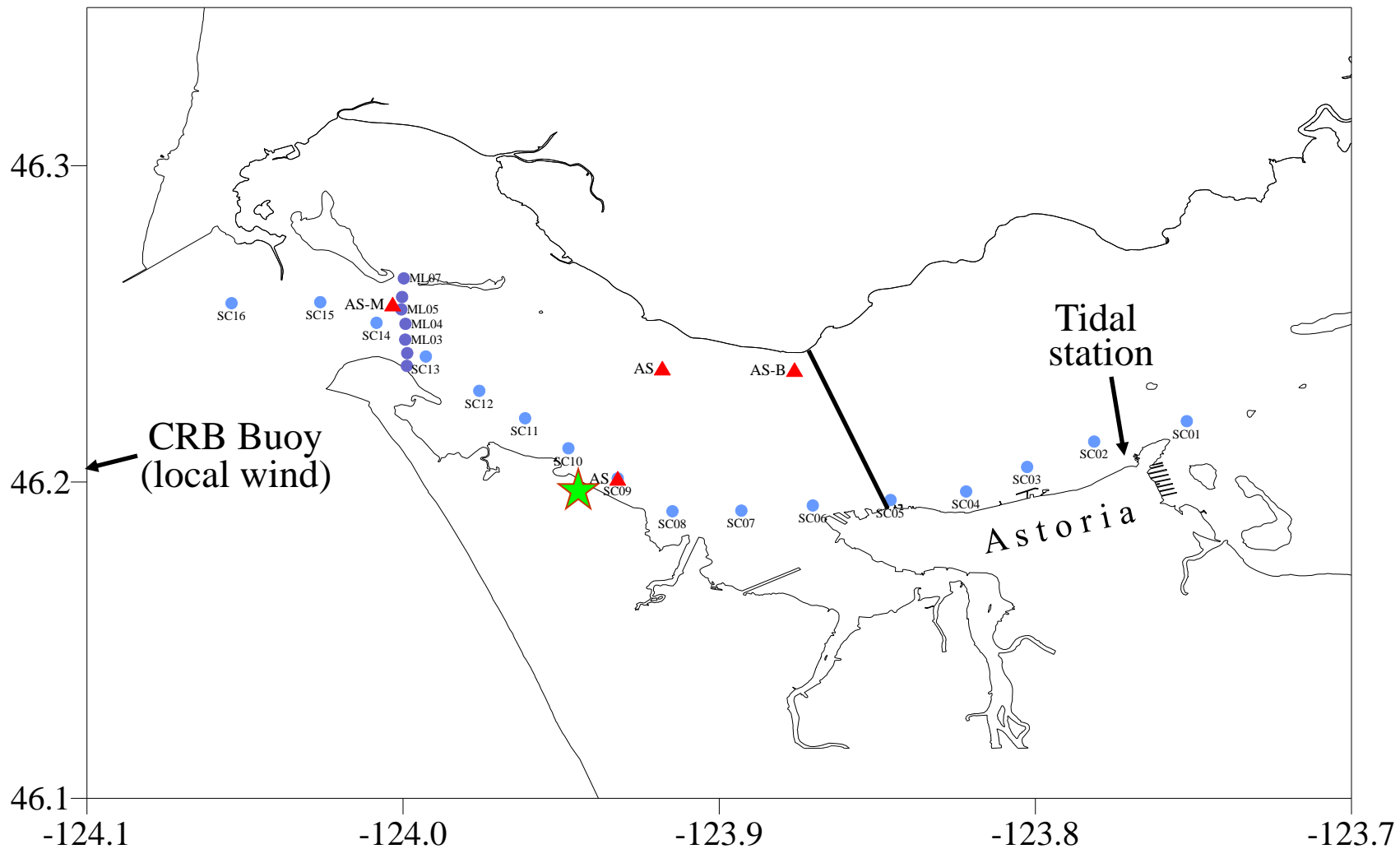
■ Moorings

- Wind
- Tide
- Saturn system (Salinity, DO, ect)

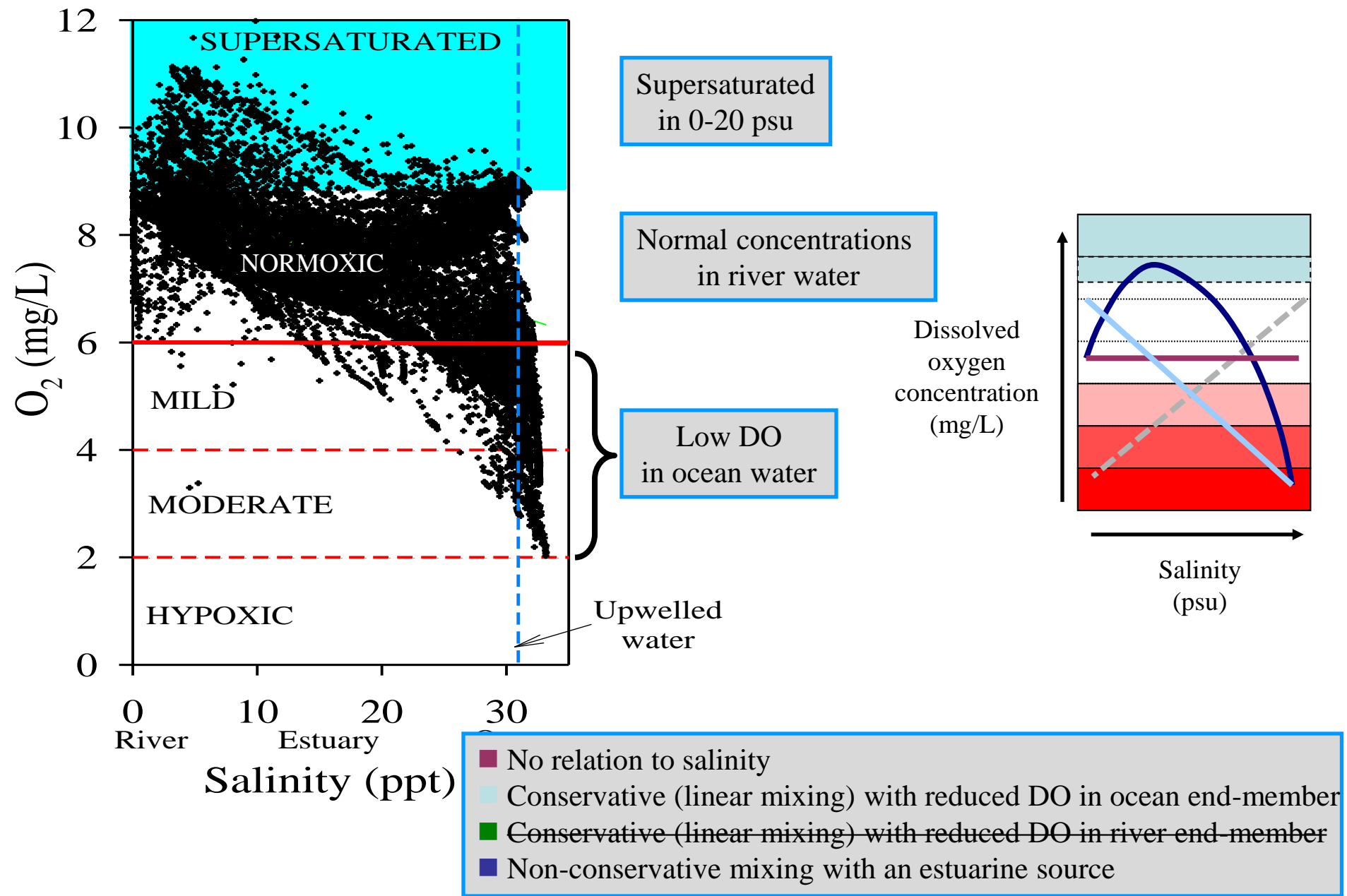


<http://www.stccmop.org/>

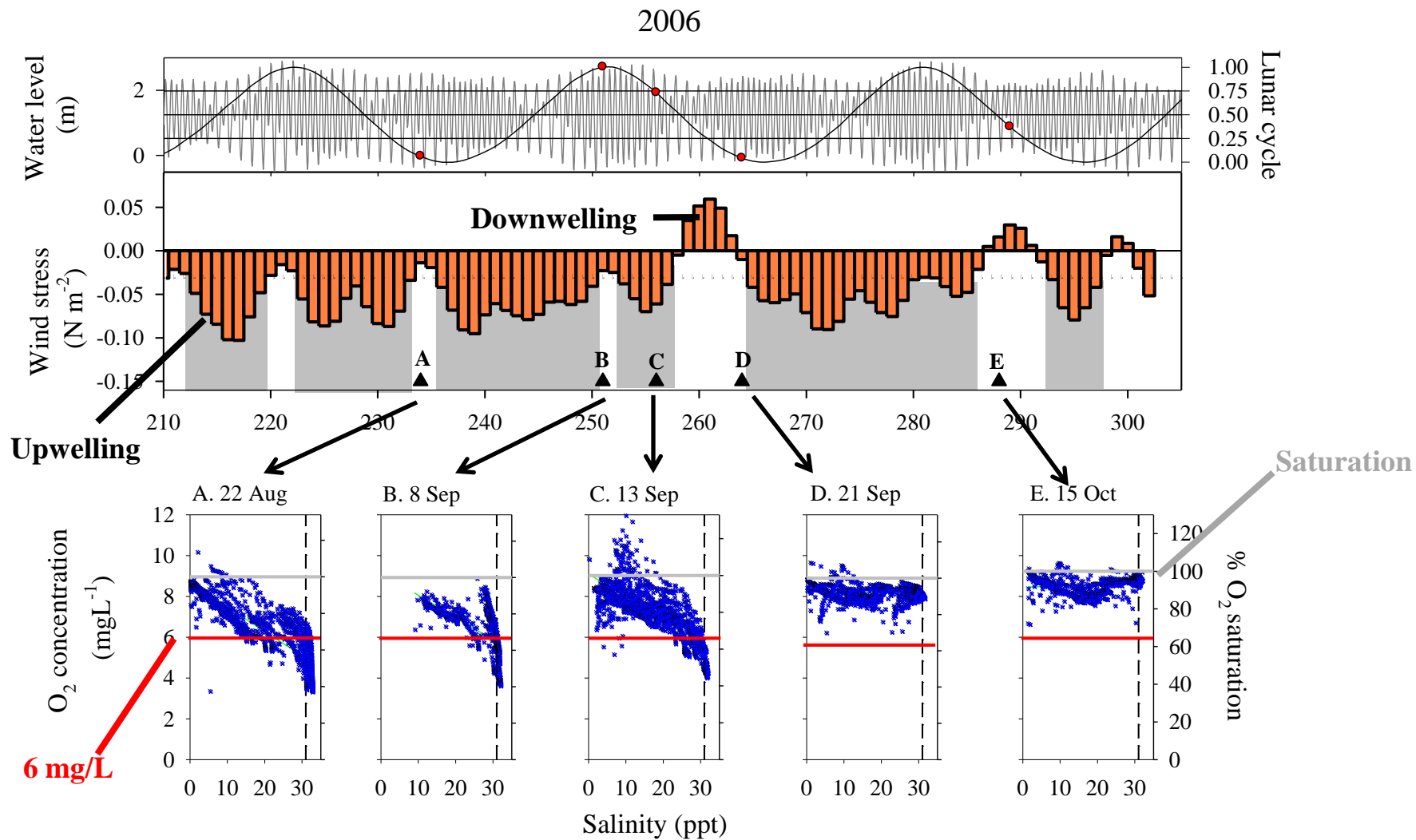
Columbia River Estuary stations



Dissolved oxygen observations in the CRE



Physical time series and O₂/salinity diagrams 2006



Depth-distance transects of salinity and oxygen: South Channel

Upwelling

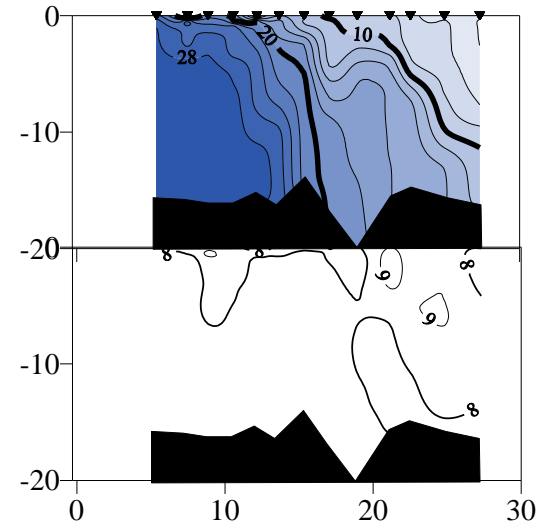
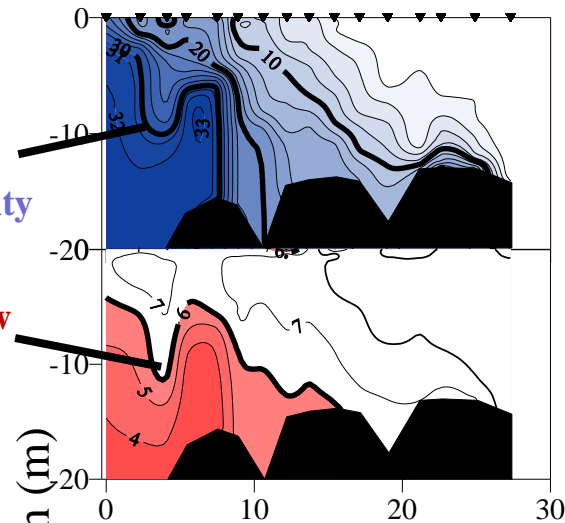
Downwelling

A. Cruise A

B. Cruise D

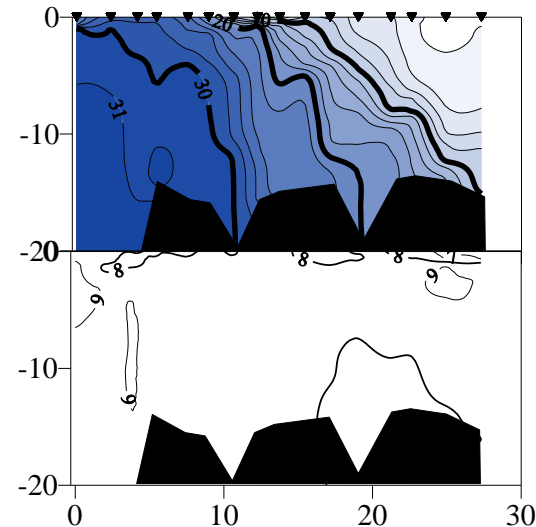
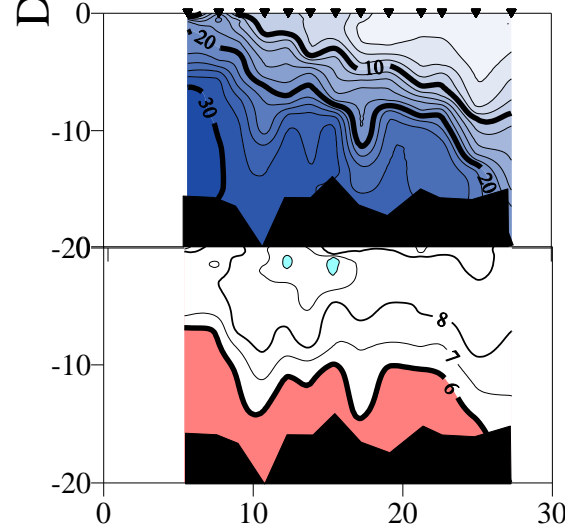
High
salinity

Low
DO

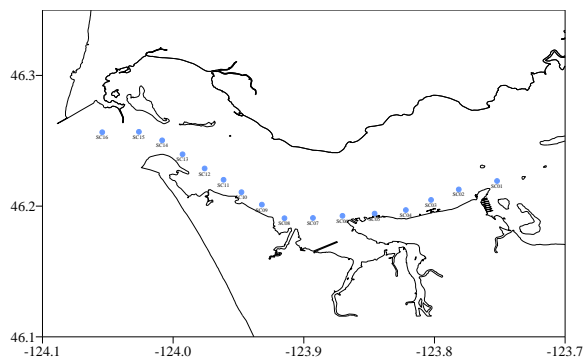


C. Cruise C

D. Cruise E



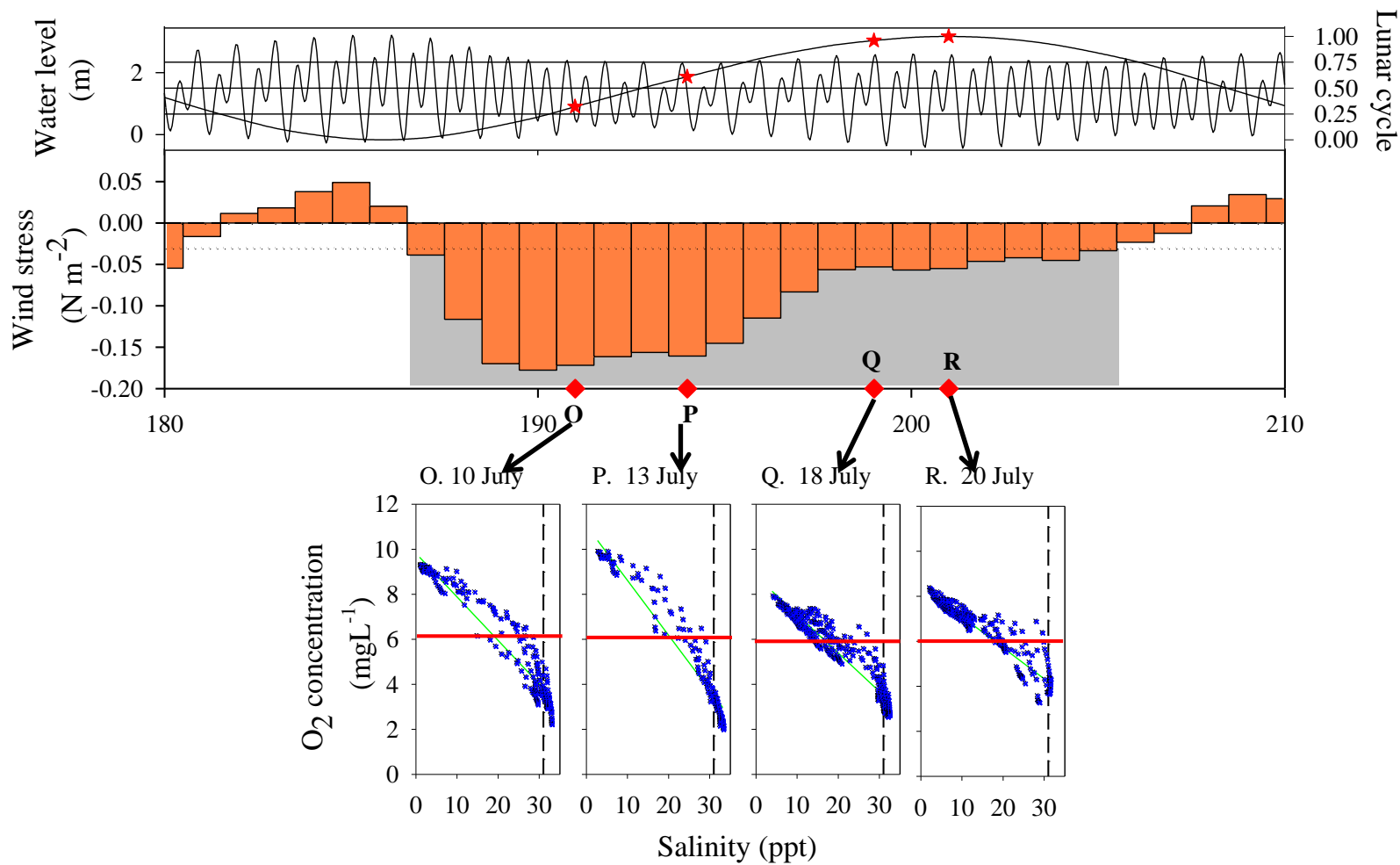
South Channel



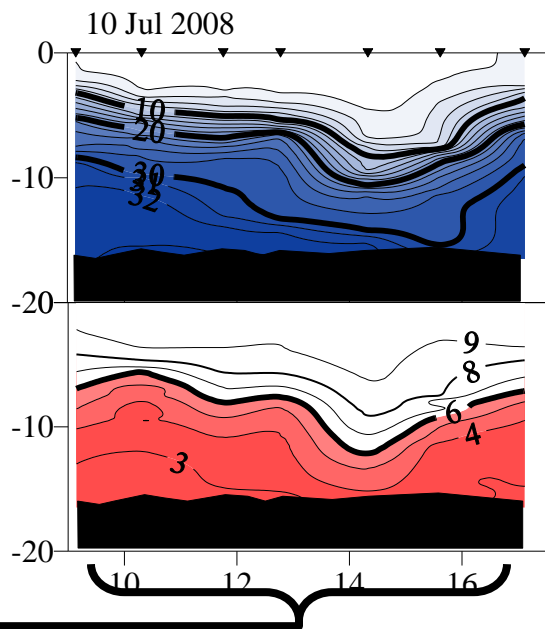
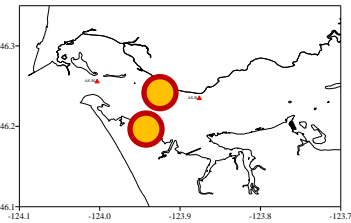
Distance (km)

Physical time series and O₂/salinity diagrams: 2008

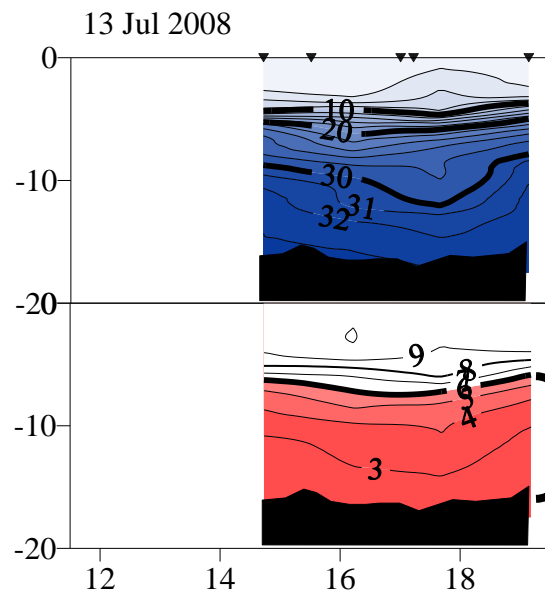
2008



Anchor station time series of oxygen and salinity

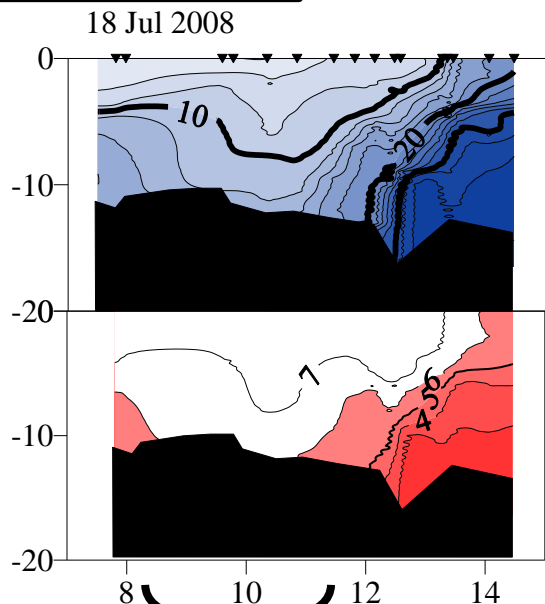


Longer duration

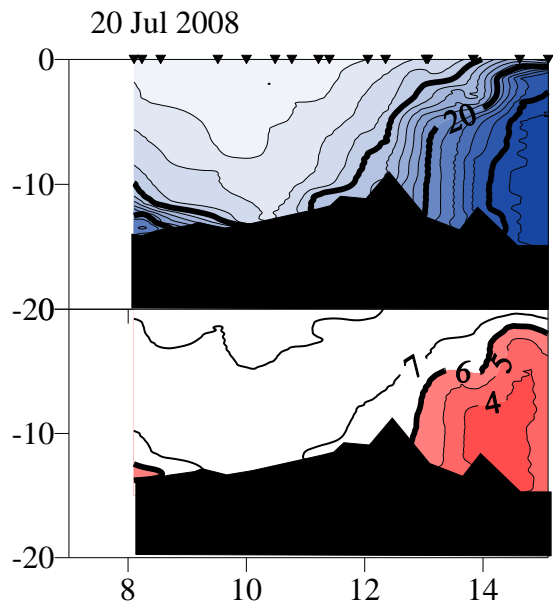


Upwelling/
Neap tide

Less vertical extent



Shorter duration



Upwelling/
Spring tide

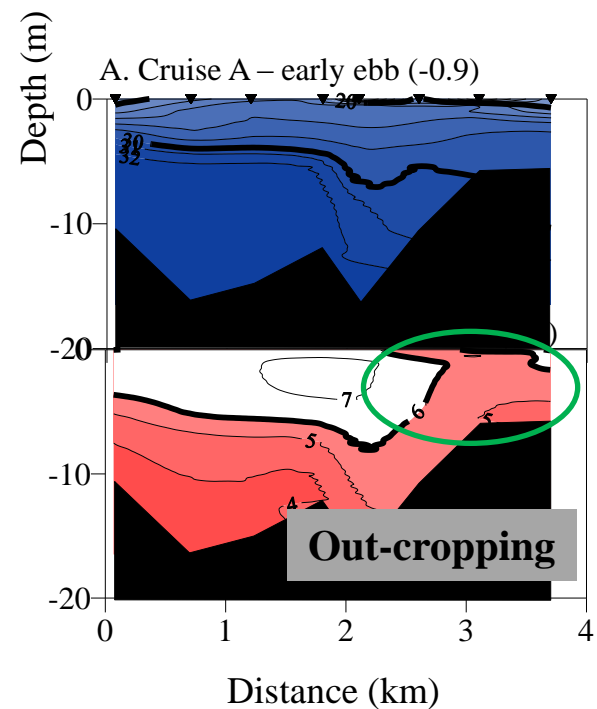
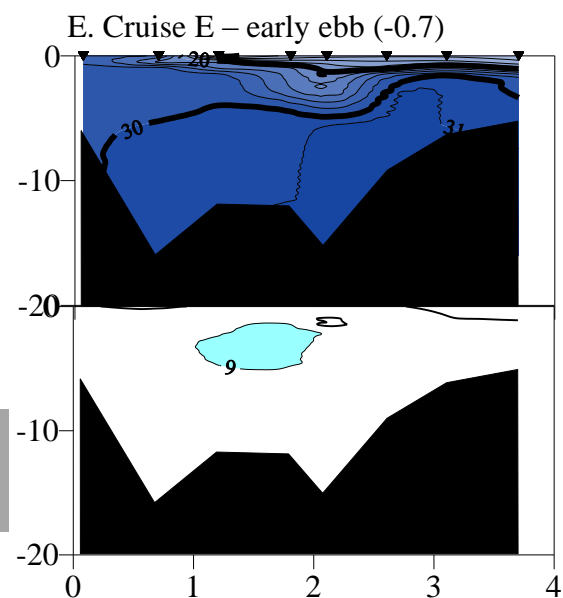
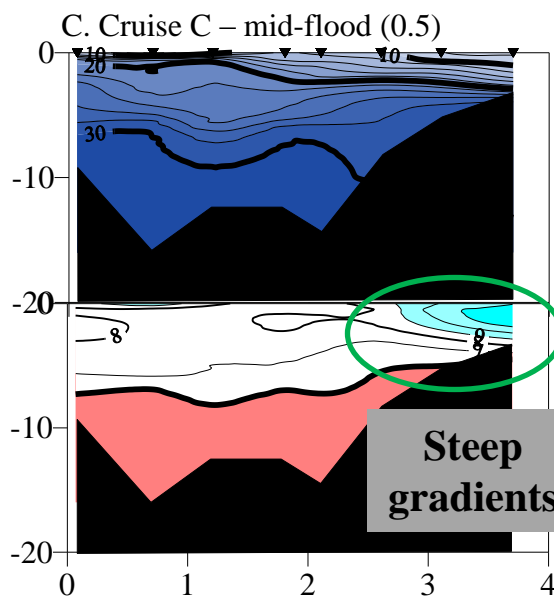
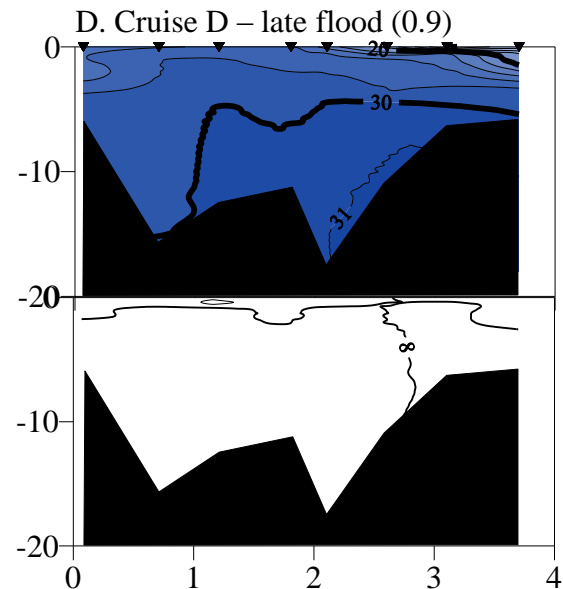
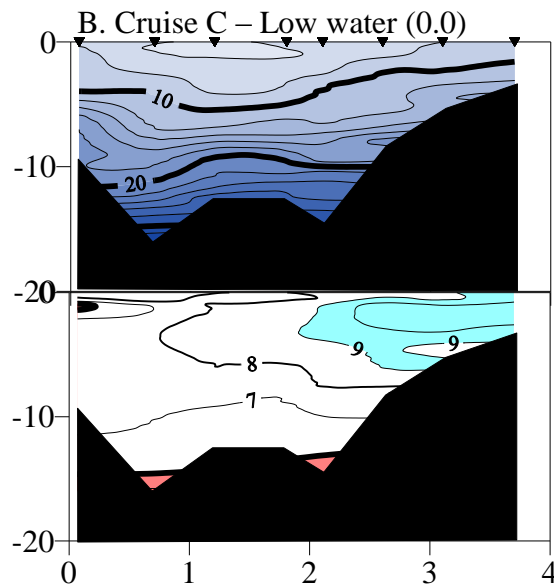
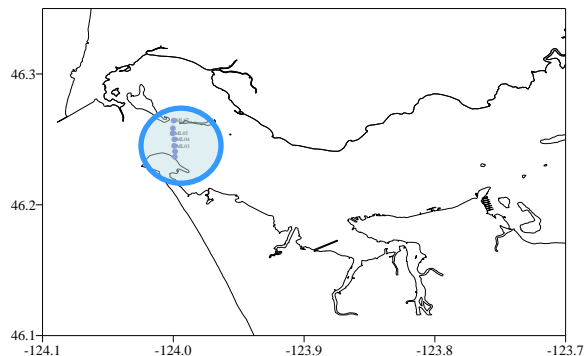
Greater vertical extent

Time of day

Cross-channel transects: semidiurnal tide variation

Upwelling

Downwelling



**Steep
gradients**

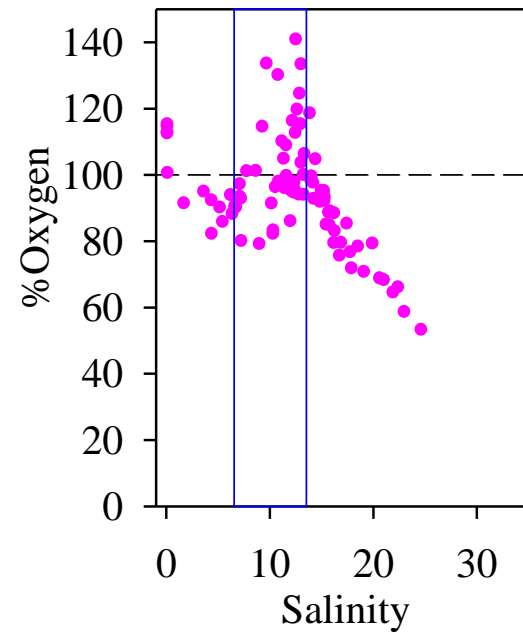
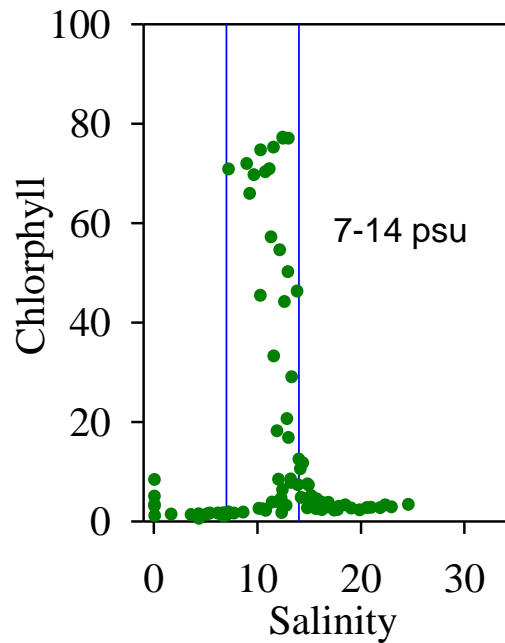
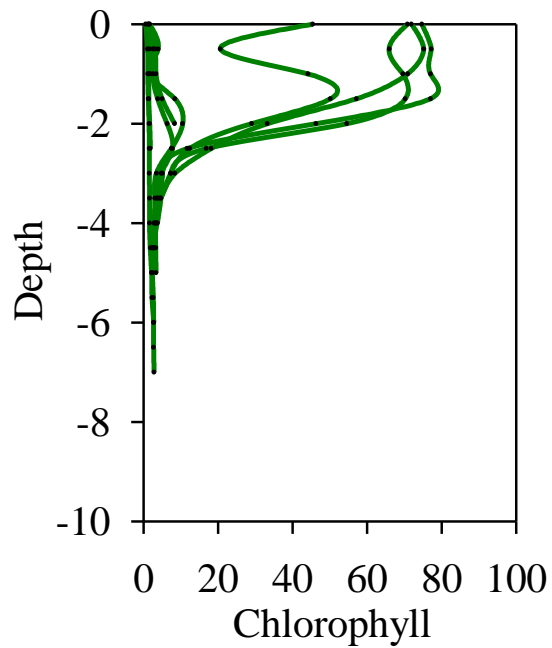
Distance (km)

Dissolved oxygen source, a mixotrophic ciliate

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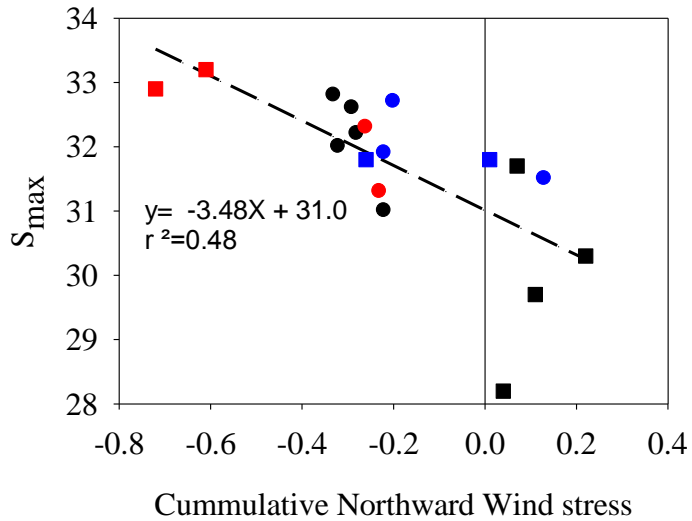


Dissolved oxygen source, a mixotrophic ciliate

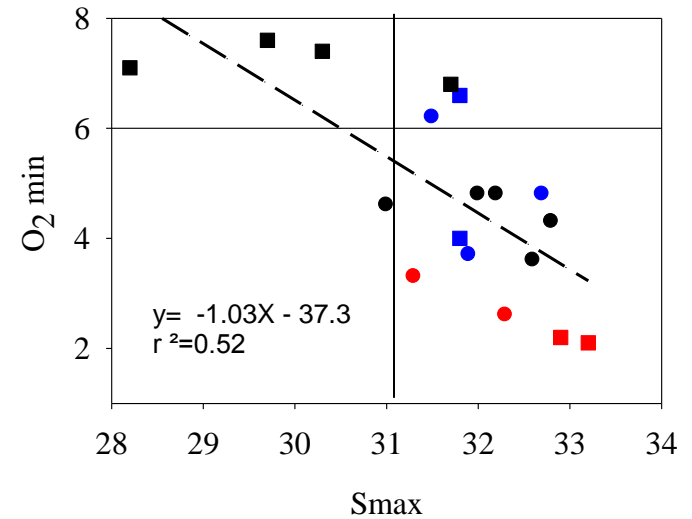


Correlation of physical indices

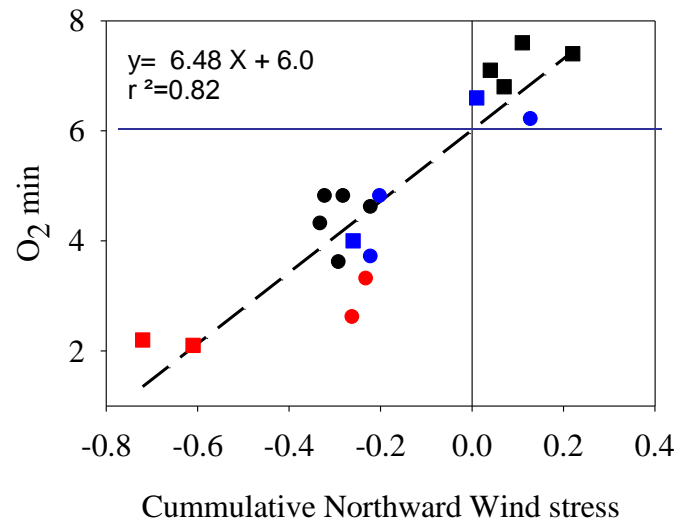
Maximum salinity vrs wind stress



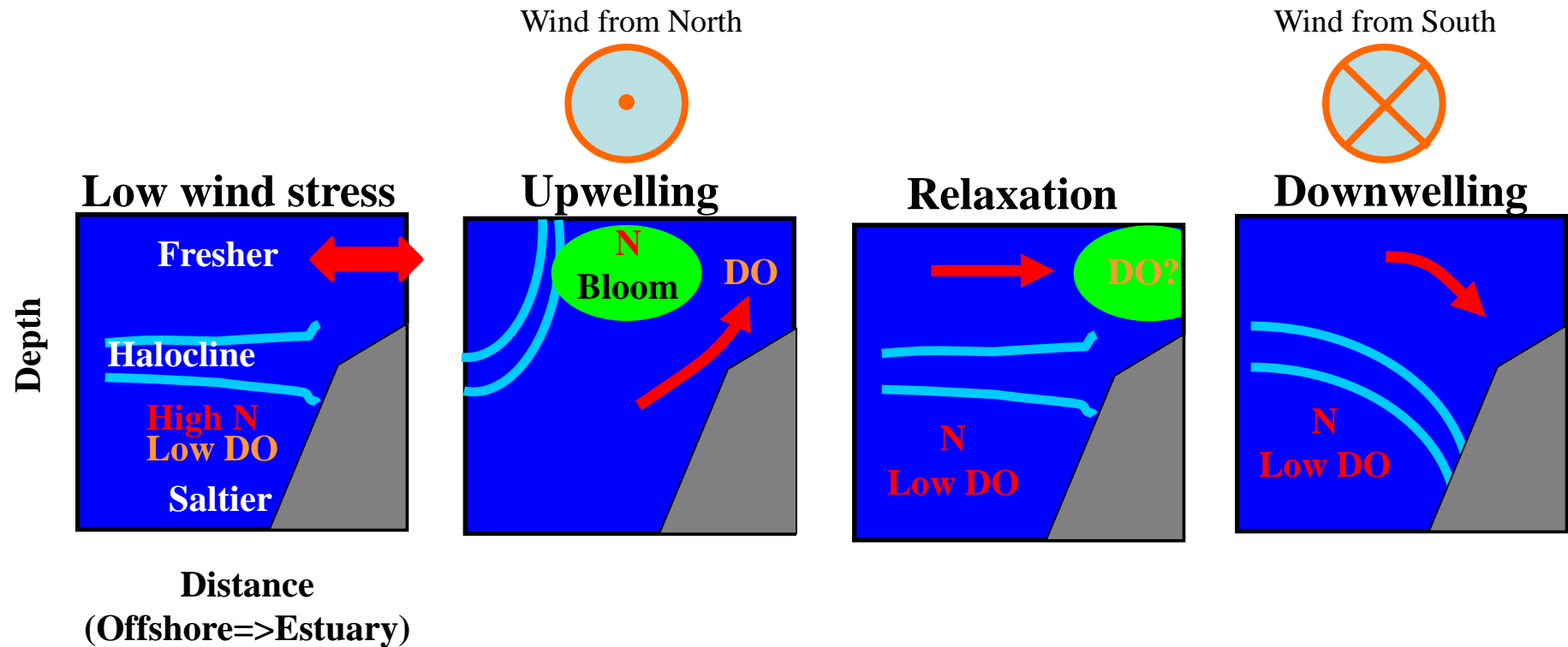
Minimum O2 vrs Max Salinity



Minimum O2 vrs wind stress



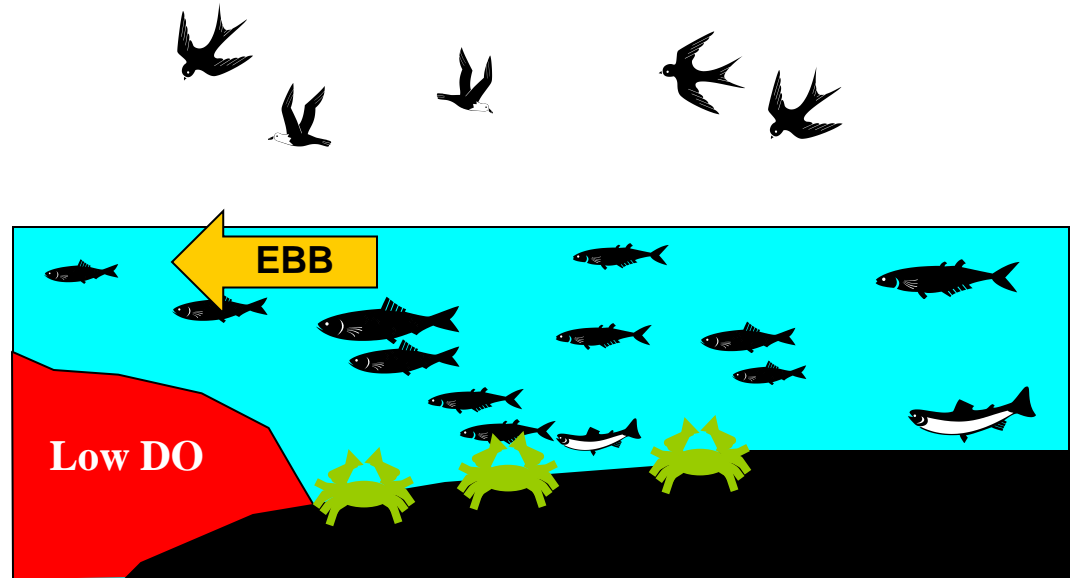
PNW: Strong ocean-estuary linkage modulated by upwelling dynamics



- Estuaries “sample” nearshore water sources
- Upwelling can deliver high salinity & low DO to estuaries
- During relaxation, ocean productivity transferred to estuaries
- Downwelling (surface) typically has lower salinity and higher DO
- Low DO prevalent during summer upwelling season

Consequences for salmon and crabs: Spring tides

- Definitions
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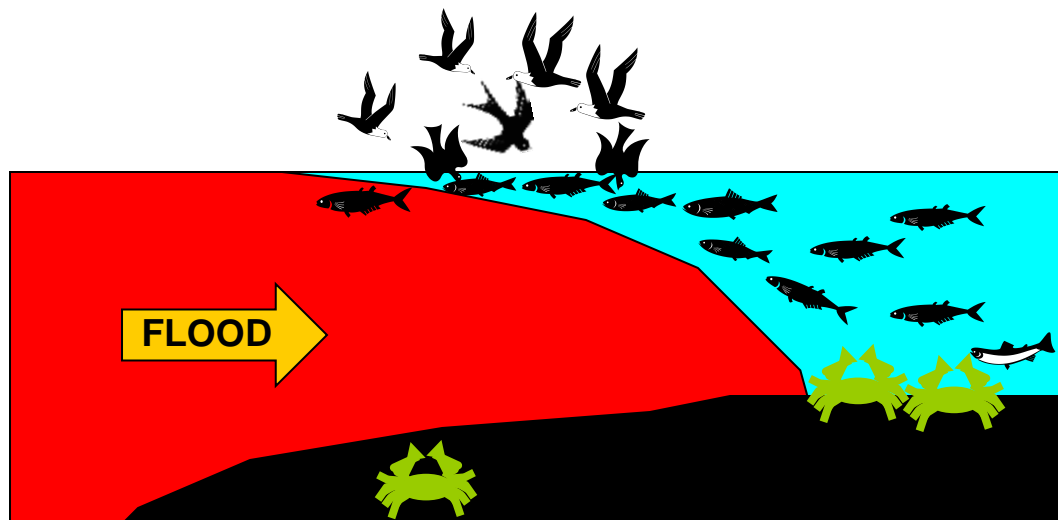


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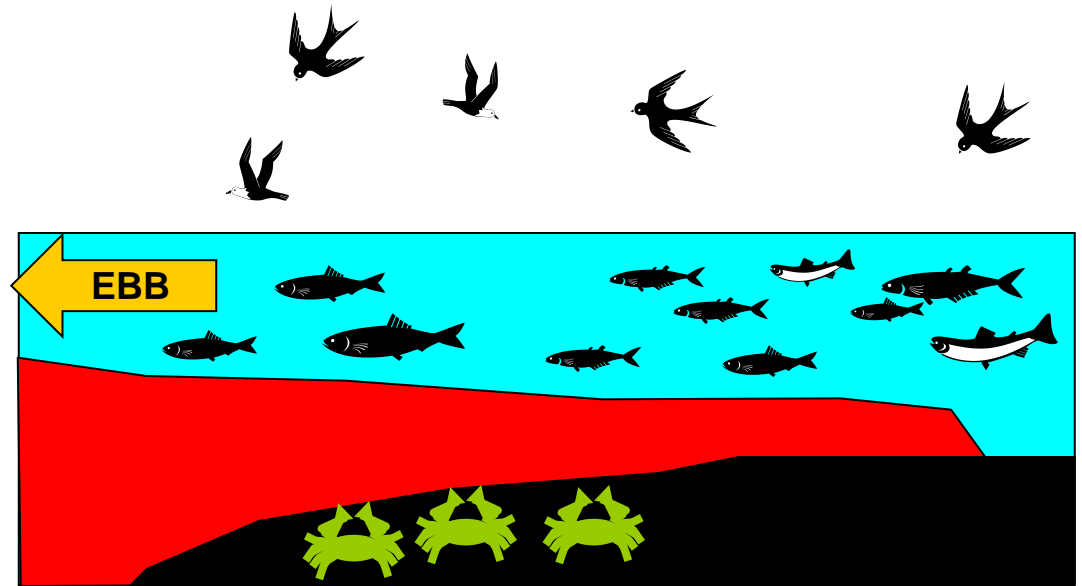


- Fish: Vertical displacement
- Crabs: Horizontal displacement
- Periods of vulnerability



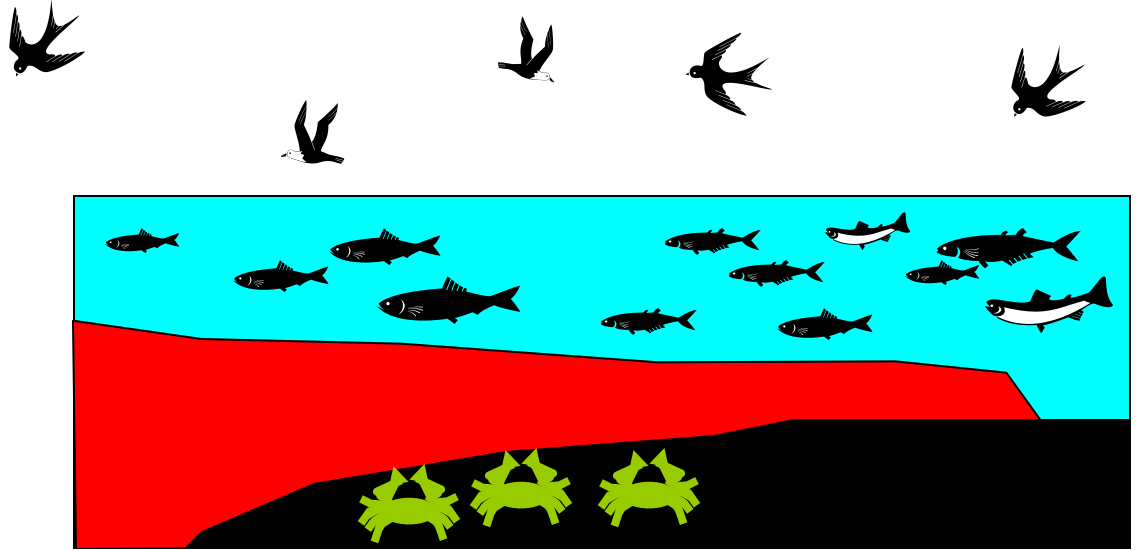
Consequences for salmon and crabs: Neap tides

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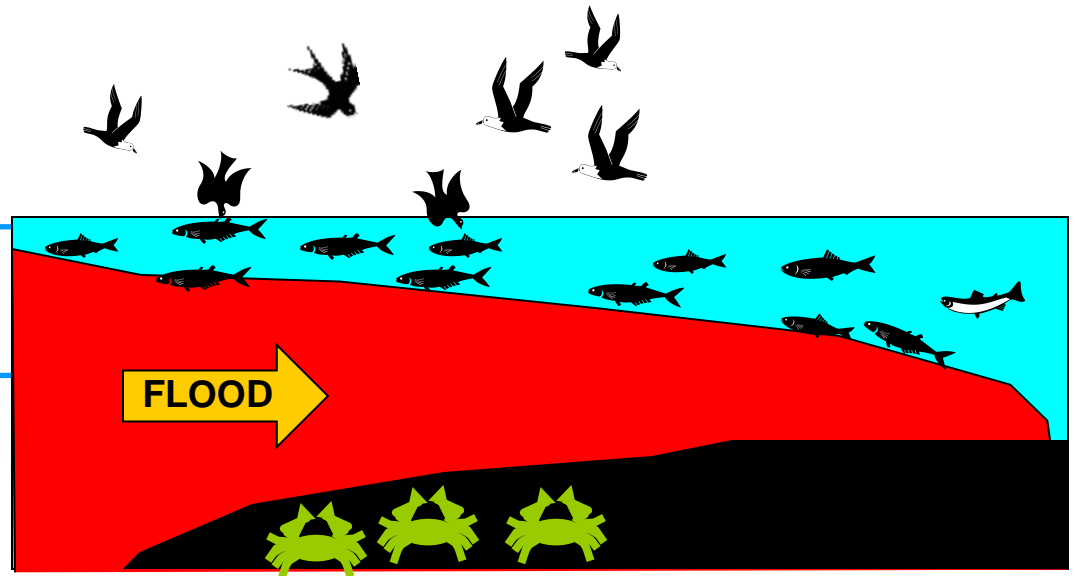


Consequences for salmon and crabs: Neap tides

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- Fish: Vertical displacement
- Crabs: Temporal displacement



Summary

- Low DO is entering the CRE and other PNW coastal estuaries
- Low DO water generally has reduced pH (acidic)
- Source of low DO is upwelled ocean water - River water was always normoxic (in mainstem)
- Recorded values were in the moderate biological stress range – no hypoxia (yet)
- Even so, recorded values likely induced adverse behavioral and physiological effects on salmon and crabs: **Effect on CONDITION & SURVIVAL??**
- Based on the number of wind events each year, there could be significant impacts on biota
- Predictions are for worsening future conditions

Management implications

- Cannot prevent – can defend
- Update and maintain coastal monitoring observatories like SATURN
- Minimize impact to aquaculture facilities
- Time salmon releases from hatcheries with favorable DO conditions

Thanks to my once and future CMOP collaborators Joe Needoba,
Antonio Baptista, Ben Li, Lydie Herfort, Charles Seaton,
& captains and crew of Forerunner



Consequences?

Bottom exposure : Semidiurnal Tidal scale

Cruise ID	Station	Study length	DO category		
			>2-4	>4-6	>6-10
B	NC07	4.7	17.0	53.2	29.8
J	NC07	8.4	0.0	0.0	100.0
K	NC14	9.0	0.0	0.0	100.0
M	NC14	7.6	0.0	55.3	44.7
N	NC07	7.8	17.9	61.5	20.5
O	SC09	7.9	100.0	0.0	0.0
P	SC09	4.5	100.0	0.0	0.0
Q	SC09	4.9	46.9	13.9	39.2
R	NC10	7.0	11.4	15.0	73.6

- Longer exposures at bottom during neap tides

Interannual scale (Model)

Year	Events	DO Category	Days	% Time
2006	6	0 to 2	4	1.9
		>2 to 4	48	22.9
		>4 to 6	100	47.6
		0 to 6	152	72.4
2007	9	0 to 2	1	0.5
		>2 to 4	27	12.9
		>4 to 6	75	35.7
		0 to 6	103	49.0
2008	11	0 to 2	8	3.8
		>2 to 4	31	14.8
		>4 to 6	95	45.2
		0 to 6	134	63.8

- Interannual variation
- Hypoxic conditions rare
- Biologically stressful conditions common

Physical time series and O₂/salinity diagrams: 2007

2007

